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Flight of birds.

(1858)

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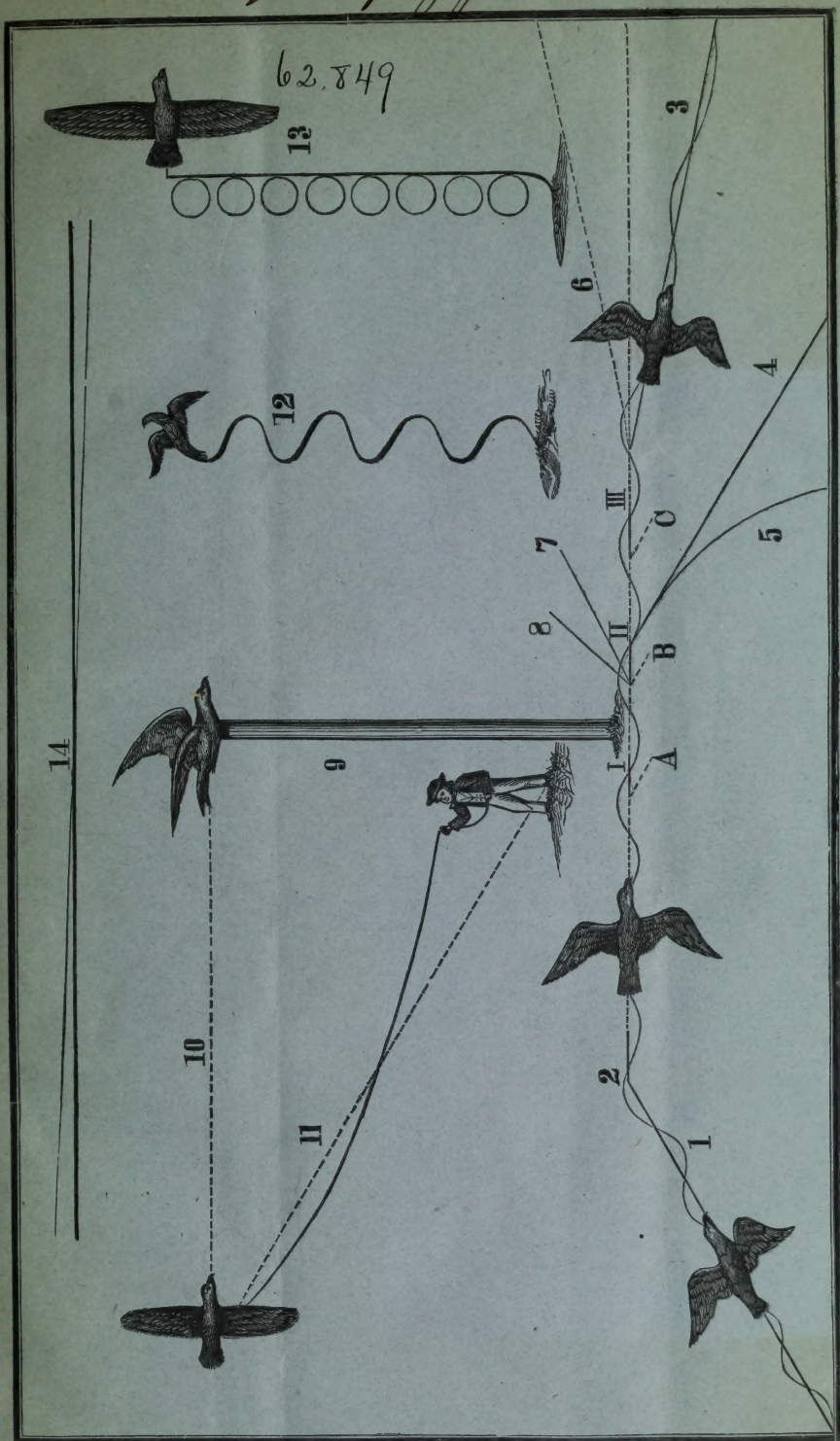
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A NEW THEORY

OF THE

FLIGHT OF BIRDS,

BY

R. O. DAVIDSON.

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1858.

A New Theory of the Flight of Birds.

BY R. O. DAVIDSON.

PHILOSOPHY, in the highest and most appropriate meaning of the term, is the key (to employ a simple metaphor) with which wise men unlock the doors leading into the occult recesses of Nature's limitless empire, where alone can be discovered her elemental principles ; the secret germs of her countless organisms ; the *vis inertia* of her grand systematic revolutions, and the laws of her simple motions. But, it is quite certain that there is about an equal portion of truth and error mixed up in the mass of philosophy, so called ; and generally, it is as difficult to detect and remove old errors, as to discover and establish new truths throughout the vast fields of physical and metaphysical science. And among the great number of prominent subjects which, hitherto, have claimed the attention of philosophers, there is none which is so constantly open to view, and that has been so long and attentively observed, with the discovery of so little of truth, as that of our present inquiry—the *flight of birds*.

The cause of this, I imagine, is to be found in the nature of the various circumstances connected with the production of this motion, consisting chiefly in the great velocity of the animal on the wing ; his remoteness from the observer ; the airy and unsubstantial medium in which it occurs ; and the peculiar form, flexibility and celerity of motion of the organs by which alone it is, seemingly, produced. At any rate, from these or some other cause, it is certain that men of science, and all others, have utterly failed to solve the lofty problem, “the way of an eagle in the air.”

There are several varieties or modifications of this motion, each of which occurs under, and is controlled by, particular circumstances ; such as that of *ascending*, progressing on *horizontal lines*, and *descending* under the action of the wings ; and the exhibition of similar

movements of the animal with the organs of motion merely expanded. And there is a corresponding variety of forces concerned in producing these results, such as that of *gravitation*, *muscular* power, *acceleration*, and the *force of the winds*. And in the process of what may be called flight proper, contrary to the popular belief and the results of all previous investigations, I have discovered that the first named power exerts the chief influence. And in order to show clearly the difference between my own theory founded upon this principle, and that of the current philosophy on this subject, I will here present the outlines of the latter hypothesis, and then proceed to give a true explanation of the phenomenon of flight, contained in two somewhat distinct parts, one of which will be illustrated by a diagram.

The vague and unsatisfactory theory of the flight of birds found in the books, is based upon the supposition that *gravitation*, or the *weight* of the animal, is the great obstacle to be overcome in this process; and in order to meet this difficulty, the authors of it were driven to the further supposition, that the bird is capable of exerting through the pectoral muscles an enormous amount of strength for so small an animal; and having thus inferred the means of attaining the proper elevation, it was finally imagined, that, by imparting to the wings an *oblique movement*, the effect of which must be both to sustain the weight and propel the body, they *jumped* to the conclusion that these were the means, and this the philosophical solution of flight proper!

And in accounting for certain curious evolutions in the air, performed by some of the large winged species only—such as that of ascending by gyratory movements, and of sailing far away on straight lines, without any other effort than that of merely expanding the wings—naturalists profess to have discovered a nameless gas which, they say, is secreted within the hollow ends of the quillfeathers; that all birds in the process of breathing have the peculiar power of inflating with air a large internal membranous duct extending throughout the length of the spine, and also the cavities of all their bones, and of exhausting both at pleasure; and each of these marvelous means is supposed by this theory to play an important part in producing those graceful movements of the bird on the motionless wing.

Such is a brief but truthful statement of the chief elements of the

popular theory of the flight of birds; and upon this fallacious basis it has long stood, undoubted and undisturbed by any one, so far as I know, besides myself.

Now, I object to this manner of philosophizing on this subject, and along with the process of reasoning, I also reject the hypothesis as alike untrue. For I am well assured of the soundness of my convictions, derived from long and careful observation and reflection, that gravity, instead of being an obstacle, is the true foundation and chief force by which flight proper, and all its modifications are effected. And, adopting an entirely different process of investigation from that just stated, I will now proceed to make a brief exposition of my new theory—based upon three leading propositions containing its principal elements, arranged in, what I consider, both their natural relation and logical dependence—and constituting the first part of it. They are as follows :

First, That the influence of gravitation is the primary and efficient cause of the progression of birds on the wing.

Second, That the wings in flight are exerted vertically, the chief effect of which is, to raise and sustain the animal in the air.

Third, That the velocity attained in flight proper, is incidental and that it equalizes the power exerted in imparting motion to the wings, in proportion to the weight carried, with that employed by all other animals in their respective modes of locomotion on the earth and in the water.

These propositions, according to my conceptions, embrace the three most important elements in the process of flight proper, and I will endeavor to elucidate them by the aid of such powers of reasoning as I can command, founded on the constant exhibitions of this motion as they usually appear among those species of the feathered tribe which fly the fastest and continue longest on the wing.

During a period of twenty years, since my attention was first directed to this subject, I have constantly observed that, among those birds whose weight and area of wing bear such a relation to each other, as to require in the process of flight three or more strokes of the latter, per second of time, when one such is in the act of starting from the earth's surface, he makes a vigorous effort with both wings and legs, whereby he fairly launches himself, so to speak, within the aerial medium, and also imparts to his body considerable motion in

the particular direction he designs going: and that, so soon as the effect of such effort to elevate the weight ceases, the animal instantly begins to gravitate towards the earth, not perpendicularly, but in a slanting forward direction, while at the same time, by a gentle exertion of his organs of motion, as seen in short excursions, he is enabled to maintain the desired height whilst moving through the air with his usual velocity. If, however, the object be to rise high above the earth, as in preparing for long migrations, the wings are exerted with greater celerity and power, the head and fore part of the body being slightly raised, and for a short time he struggles upward with a rapid motion. And in thus *ascending*, it may be fairly inferred, I think, that the body acquires a considerable degree of momentum, which, while it imparts uniformity of progress upon the line of ascent, also relieves the animal from the labor of sustaining his full weight after the first few vigorous impulses of his wings. But still, it is equally probable, that the power employed in this process, exceeds the amount expended in flight proper, as much as that which must be exerted by a person in climbing a steep mountain transcends the amount required in the usual manner of walking on a level surface. And, at any rate, it is evident, that in all such cases the labor is so great that both men and animals soon become exhausted, as is proved by every day experience with reference to ourselves, and as is equally certain, from the strongest rational inference, in regard to birds.

The desired elevation having been thus attained by the migrating birds, let us now consider the process of flight on a horizontal line, as exhibited in their motion whilst traversing large districts of country, in passing and repassing to and from the places which they frequent in winter and summer. After slightly relaxing the power by which one of these animals raised himself, and adjusting his body in a level position on the line of motion, he instantly begins to descend on a certain angle formed below that line—resulting in each case from the comparative area of wing and weight of body—under the increasing influence of *gravity*, while the equally constant action of the organs of motion effectually counteract that tendency; and in the conflict between these two forces, the body incidentally moves in a forward direction, and whilst thus progressing on a horizontal line soon acquires a considerable degree of *accelerated motion*, which, resulting from and combining with the influence of gravity, impels it onward in a still

atmosphere at the rate of one hundred miles per hour. And so long as the wings are exerted with sufficient celerity to sustain the animal on the line of motion, he remains in this situation without any change in the degree of his uncontrollable velocity.

So much for the present, in support of the assumption contained in my first proposition—"That the influence of gravitation is the primary and efficient cause of the progression of birds on the wing." And in regard to the precise manner in which the wings are exerted in flight proper, and the true effect thereby produced, as stated in my second postulate, I remark, in the first place, that the full realization of the truth of what has just been said is sufficient in itself, it should seem, to satisfy every intelligent mind, that nothing more than the simple *vertical action* of those organs is required in this process. But not so; on the contrary, naturalists and philosophers generally, contend that volant animals *propel* themselves through the atmosphere by an *oblique movement* of the wings, in a similar manner to that of the fish in forcing his body through the water by the exertion of the tail-fin. And which, in turn, I deny, and hold that there is no such similarity in either the principles, or the manner of effecting these two motions. This position may be readily sustained by a brief reference to the circumstances in which they respectively occur, and a simple contrast of the manner of exerting the wings in the one case, and the fin in the other.

It will be perceived from a single glance at this matter, that the condition of things, in all the essential particulars, as connected with the locomotion of these two animals in their appropriate elements, so called, is widely different.

And in consideration of the single fact, that the specific gravity of water is about eight hundred times greater than that of the atmosphere, it becomes evident at once that the principles of motion in these two fluids are, or ought to be, entirely distinctive. The density of the water of itself, sustains the weight of the fish without any effort on his part; while, on the other hand, the atmosphere will not support the smallest feather detached from the body of the bird. And hence, in traversing the water, whether beneath or upon its surface, *propulsion* is the principle of motion, and which, as exhibited in the swimming of the fish, is effected by means of the tail-fin exerted against the surrounding fluid, first on one side, and then on the other,

and thus forcing the body through and overcoming the resistance of the medium in which it floats. But not so in the atmosphere. Here, from the great rareness of the medium, it is absolutely necessary to impart to the wings in flight *vertical motion*, the chief effect of which is simply to *raise* and *sustain* the weight of the animal in opposition to the constant influence of gravity, ever tending to reduce him back to the earth, as already partially explained. It follows from this, that the fish exerts the tail-fin in a *horizontal direction*, and thereby *propels* himself through the water, there being no necessity for a *sustaining power* in the process of swimming; and that the bird imparts to his wings *vertical movements*, and thereby *raises* and *sustains* his weight in the air, there being no necessity for a *propelling force* in the process of flight. And thus, the supposed identity of these two cases vanishes like the shadow of a flying cloud.

Every just consideration of this subject goes to show, that the bird ought not to propel himself in flight; but the leading and most powerful one, is, that there is no necessity for such an effort in producing this motion, and if required, it is equally certain, that it would be impossible to make it under the circumstances of the case, as I will now endeavor to show.

It is generally supposed that there is a double effect produced by the action of the wings, the one *sustaining* and the other *propelling* the animal, under the popular idea that the laws of mechanics require the latter influence in this, as in all other cases of transient motion. But this is a great mistake; for if the back extremities of those organs were either intentionally, or from the pressure of the air beneath in making the downward strokes, incidentally raised, (and this must take place to produce the effect claimed,) they would retard instead of aid in effecting this motion; because, the slightest elevation of those portions of their surfaces above the level of the front outlines, from the force of the air through which they are carried with great velocity by the body, thus brought in contact with them, would result in the double injury of constantly depressing the animal below, and hence seriously impede his progress on the line of motion. And were it possible in this process to elevate those portions of the wings, as required in the supposed oblique movement of them, without producing these injurious consequences, no sort of advantage would result from it, as will clearly appear from the following statements.

It is known to all persons informed on general subjects of natural philosophy, that all birds of extensive flight, such as the eagle, wild goose and duck, usually progress at the rate of from seventy-five to one hundred miles per hour in a still atmosphere ; and, at this velocity, (as may be ascertained by a simple calculation,) they traverse the space of from one hundred and twenty to one hundred and forty-five feet per second of time. Hence, from this simple statement it is evident that those animals cannot exert their organs of motion in the manner stated, with sufficient celerity to act upon the air to any useful purpose, whilst being borne along at such a rate by the body.

Such an effort made by the bird, with the design of propelling himself while continuing on a horizontal line, would be similar to that of a person endeavoring to row a boat against a current of water which moved by him with greater velocity than that he could impart to the oars. At each dip of the paddles into the water, instead of effecting the desired object, those instruments would be dashed out of his hands by the rushing stream. And so in flight ; each turn of the wings, whether intentional or incidental, would only result in obstructing the velocity of the animal, by presenting their broad surfaces, or portions of them, to the force of the impinging atmosphere, which would instantly dash the parts thus exposed down to a level position, and to that extent disturb his equilibrium and impede his motion.

And finally, the peculiar form of the wings being concave on one side and convex on the other ; strong and unyielding in the greater portions of their front, and attenuate and elastic throughout the back outlines ; their relation to, and position upon the body when spread, and their *vertical action* in flight—the latter being so easily observed and obviously necessary, it is remarkable that men of science especially, should have so long failed to discover the inevitable effect resulting therefrom ; the constant influence of gravity upon all bodies in motion on the earth and in the air alike ; and the great and uncontrollable velocity of winged animals whilst traversing the latter gaseous field of nature on a horizontal line, all of which, to a greater or less extent, are concerned in this process, when wisely considered, unitedly concur in establishing the truth of my second proposition : “ That the wings in flight are exerted *vertically*, the chief effect of which is, to raise and sustain the animal in the air.”

I now come to consider the effect of the velocity in flight proper, upon the weight of the animal, with reference to the amount of power

required in this process, in elucidation of the position assumed in my third postulate.

The great velocity of the bird on the wing is entirely due to the influence of *gravity* and *acceleration*, as already partially explained ; and the *weight* of the animal is involved in his *motion* to a far greater extent, perhaps, than has ever been suspected by any of those persons who have heretofore attempted to explain the phenomenon of flight ; and, after long observation and mature reflection on all the matters connected with this interesting subject, I can confidently lay down the following rule as the basis of my remarks upon the point under consideration, namely : *The smaller the wings, compared with the weight of the animal, (within a certain limit) and the more frequent their impulses (to the extent of at least three revolutions per second of time,) the greater the velocity, and the smaller the amount of power required in traversing the air on a horizontal line.*

The truth of this position may be readily established, I think, by a brief explanation of the organisms, respectively, of the eagle, wild-goose and duck, which birds furnish the best examples of *swift and long continued flight*.

The wings of these animals, and those of the duck especially, are comparatively small and symmetrically formed, and consequently they are enabled to fly at the rate of about one hundred miles per hour without being much affected, either in the course pursued or the degree of their velocity, by the winds.

And these, like all other birds, traverse the atmosphere on the wing with a uniform motion, being incapable of either increasing or diminishing their velocity whilst continuing on the same plane of elevation. For it may be seen by any one who will take the pains to observe the flight of birds generally, that if the action of their organs of motion be reduced by fatigue, or from any other cause, below the proper number of strokes to sustain them on the line of flight, they instantly begin to *descend* ; and on the other hand, if increased above the required rate, they merely *ascend*. Now, it may be safely inferred from this, that the amount of power employed in this process is uniform, and that it is graduated in each case by the relative area of wing and weight of the animal. What the exact amount is in any case would be extremely difficult to ascertain ; but in view of all the circumstances connected with the production of this motion, I give it as my opinion that, among all birds similarly organized with those

under consideration, it does not bear a greater proportion to the *weight* than the numerical relation of *one* to *five*; and I am sustained in this view by the following statement relative to this matter, and which, I understand, is regarded as being true by men of science, namely, "that the wings of birds of extensive flight are loaded with the weight of only one pound to each square foot," or in that proportion. And in repeated and careful examinations of the structure of many such birds, I have invariably found that the relative weight and area of wing conformed strictly to both my own view and the rule just cited. In the case of the largest wild duck, the weight is about *five* pounds, and the area of wing one *square foot*; and hence it may be fairly inferred, that, while traversing the atmosphere on a horizontal line, this bird exerts a muscular force equal to *one* pound only in imparting motion to his organs of flight. In that of the wild goose, whose average weight is about *ten* pounds, with *two feet* of wing, the power expended is equal to two pounds. And in that of the largest North American eagle, whose weight is about *twenty* pounds, with *four feet* of wing, the strength employed is equal to *four* pounds.

And here I close my remarks upon this important element in the process of flight, after having shown, as I think, the truth of my third proposition—"that the velocity attained in flight proper is *incidental*, and that it equalizes the amount of power exerted in imparting motion to the wings, in proportion to the weight carried, with that employed by all other animals in their respective modes of locomotion on the earth and in the water."

Having now passed rapidly over the whole field of flight proper, I will conclude the first part of this inquiry, with a restatement of the process by which that motion is produced, disconnected with the reasons and illustrations adduced in support of the theory.

In the foregoing description of the manner in which the bird starts from the earth and ascends to the proper elevation for making long excursions on the wing, it will be remembered that, after having explained how he attained that position, he was left *in transitu* on a horizontal line. And now, returning to and considering him as still being on the wing, he may be justly regarded as a falling body, constantly interfered with and diverged from the line of perpendicular descent by the vertical action of the wings, resulting in a constrained tendency of his body towards the earth in the direction of a point at a considerable distance in front of him, and thus indefinitely pro-

longing the time of his fall, while progressing on the line of motion at the rate of one hundred miles per hour, produced alone by this irregular tendency downward and acceleration, and controlled entirely by the resistance of the medium through which he moves, and which necessarily involves a large portion of his weight in his velocity, and thereby reduces the amount of power required in this process, compared with what was necessary to overcome his inertia on starting from the earth, so far as to enable him thus to continue as long as bone and muscle can endure this kind of gentle exercise—during a whole day, or even to the extent of making a great circuit around the earth—yes, and forever, if it were possible to continue the required celerity of wing.

But usually, when coming within sight of the place of destination, this species of birds effect their descent by merely relaxing their muscular exertion, and thus, under a corresponding reduced action of the organs of motion, the weight soon brings them to the earth. And it may as well be said here, as elsewhere, that those birds whose organs of motion are very large in proportion to their weight, always descend on the motionless wings which, from their greatly extended surfaces, sufficiently resist the influence of gravity as to make the fall gradual ; while at the same time, from the flexibility of the back portions of them, they assume the form of two inclined plans between which the body smoothly and gracefully glides towards, and when coming near the earth, it often occurs that the force of the velocity is broken by one or more cycloid movements.

I will now offer an explanation of the manner in which some of those large-winged birds, just alluded to, *ascend* by gyratory movements on the motionless wings, and which exhibitions occur almost daily throughout the southern portion of the United States. But, in the first place, I will here state the converse of the rule above laid down, with reference to the best adaptation of the organism of birds for easy-going and long-continued flight ; namely : when the wings are greatly enlarged without a proportionate increase of the weight of the animal, the number of strokes of the former is correspondingly reduced within a given time, and the capacity for rapid progression (except along with the currents of high winds) is equally lost.

And this peculiarity is strikingly exhibited in that species of the falcon commonly called the buzzard, the true process of whose graceful and noiseless gyrations on the wing I will now unfold.

To the mind of the careless observer it should seem, that this ugly bird had the power of ascending to almost any height in the atmosphere by circular movements, and of remaining in those calm and pure regions for hours at a time, without any other exertion than that of merely expanding his wings. But this attractive and beautiful exhibition, like all the seeming mysteries in nature coming within the scope of our observation and comprehension, may be easily explained by simply acquiring correct knowledge of the physical structure of this class of birds, and duly considering all the apparent as well as the probable circumstances connected with its production.

Many years ago, I discovered that these seeming "fancy flights" upon "airy nothing," were chiefly effected by the force of the winds in connection with the expanded wings; and considering their large size compared with the weight of the bird, the former containing about *three square feet area*, and the latter being about *six pounds*, I suppose, that the velocity of the current of air should not exceed, nor fall much below, the rate of five miles per hour, (a light breeze) within that region of the atmosphere where these movements occur, in order that the animal may ascend in this manner immediately over a particular spot on the earth. For I have often observed, that if the wind happened to blow at a greater velocity than that stated, the birds engaged in performing these evolutions were soon blown away into a distant part of the heavens; and, on the other hand, if the current seemed to fall short of that rate, they advanced in the direction of the point from whence it came.

Now, let us suppose that, whilst there is a current of air moving at the rate of five miles per hour from the direction of the cardinal point west, one of these birds starts on the wing at that point and makes his first circular movement around by south to east, and thence by north to the place of departure.

It will be perceived that, in passing around the southern section of the circle, the animal floats with the current of air moving eastward, the force of which, added to that of his gravitating tendency, imparts to his body considerable velocity with which he rounds the eastern point, and turning his head westward immediately comes in contact with the wind which, while it instantly checks his motion, in an equal degree gradually raises him as he moves slowly up by north towards the starting point. And thus, by many repetitions of these gyrations, making a little ascension each time in passing up the northern

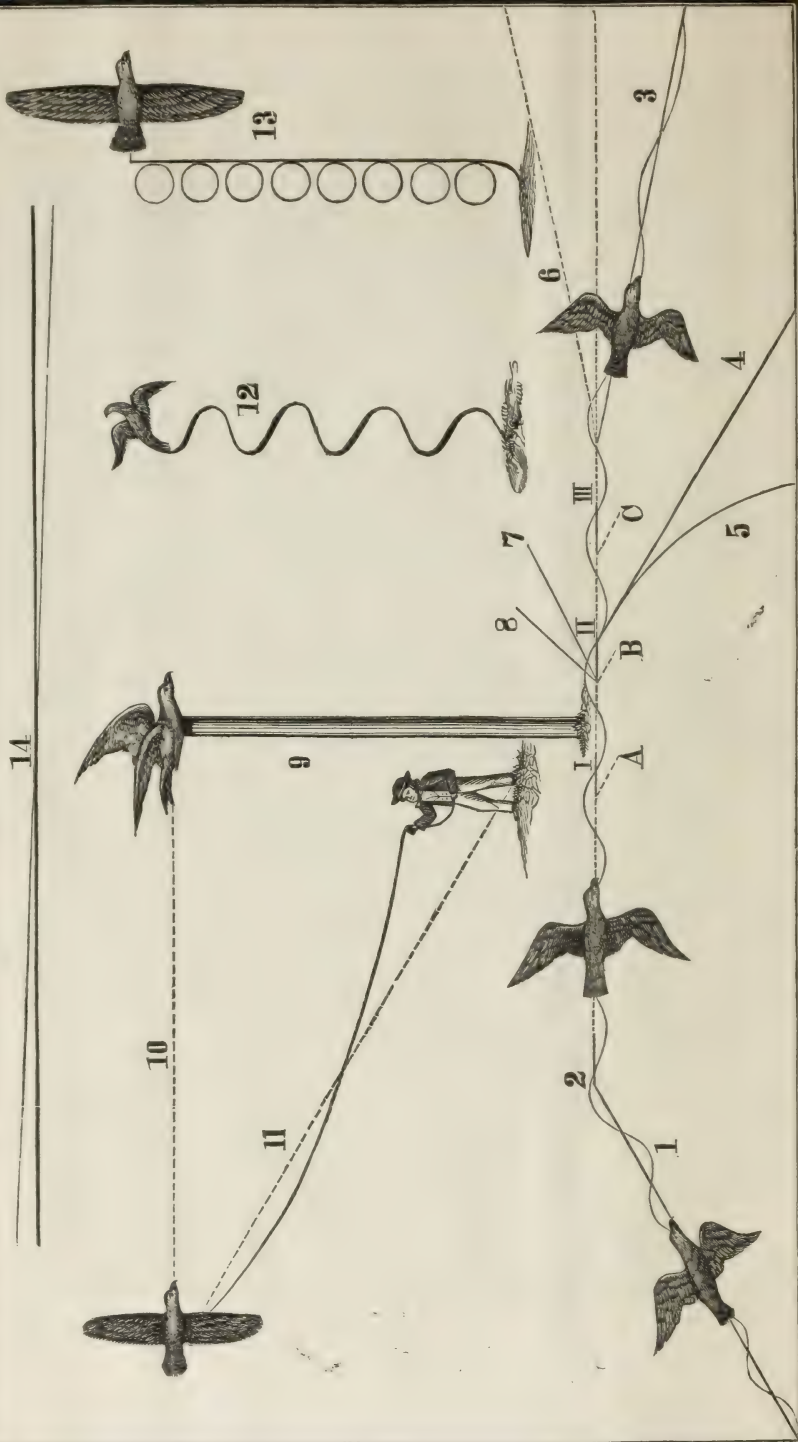
section of the circle, and losing nothing in rapidly sweeping over the opposite side, the animal at last attains the desired elevation. And then he usually sails away towards the point from whence the wind blows, progressing comparatively slow under the influence of gravity alone on a slightly descending line, the time of his fall being prolonged by the current of air which he is stemming playing under his wings ; but still, it is evident that he must soon come to the earth unless he resumes his gyratory movements, or be met by a wind of sufficient force to entirely arrest his progress for an instant, and thus find himself poised "upon airy nothing," as we often see it happen.

And finally, it will be perceived that if the foregoing theory be true, the flight of birds, as it occurs in connection with both the moving and motionless wings, is not comprehended in the three laws of motion of Newton ; and therefore it cannot be explained by reference to the principles and circumstances which govern bodies that are impressed with motion by a single impulse of either natural or mechanical forces.

Unlike all other motions, the most important process of this one, as exhibited in connection with the flapping wings, is effected by the constant influence of two opposing forces, the one being extraneous and natural and the other muscular, and of course derived from and accompanying the moving body, resulting in the origination of a third agency, not to say power, and with its influence the production of the usual swift aerial progression of birds on a horizontal line.

And the other marked feature of it, as exhibited on the motionless wing in connection with gyratory movements, is the result of two extraneous forces, the one constant and the other casual, and which at successive intervals unitedly act upon the soaring animal in one direction, and thereby impart to his body considerable velocity ; while the latter, at corresponding periods, alternately moves in unison with the two controlling forces, and in turn encounters the combined influence of both in the opposite direction ; and thus the spiral elevation of the large winged birds is gradually effected.

And these remarkable characteristics, doubtless, have hitherto prevented the true philosophical solution of this standing, or more properly speaking, *flying* puzzle to the minds of all men, both before and since Solomon's day, in whose proverbs it is said (among other things since found out) that "the way of an eagle in the air is a mystery."



PART SECOND.

EXPLANATION OF THE DIAGRAM.

- No. 1.—Represents the course of the bird in ascending from the earth preparatory to a long excursion, the serpentine line showing the path described by the tips of the wings in action at the rate of *four strokes*, per second of time ; but the angles of which, with reference to the line of ascent, are many times greater than what occurs in flight.
- No. 2.—The altitude and line of motion in flight proper ; the serpentine line here showing by its depressed angles a reduction of the number of strokes of wing *one fourth*, per second of time, as compared with No 1.
- No. 3.—The descending course of the animal under a further reduction of one stroke of wing less, per second of time, than the number required to sustain him on the line of motion.
- No. 4.—The course of the animal under an entire suspension of the action, but while sustained on expanded wings.
- No. 5.—The manner in which the body falls, after suddenly folding those organs while progressing on the line of motion, describing the parabola, like any other body in descending to the earth after having been thrown up in the air.
- No. 6.—The oblique direction in which the body constantly tends to rise above the line of motion, arising from the tendency to reaction of the straightened quills, and the muscular action of the animal whilst on the wing.
- No. 7.—The effect, on the other hand, of imparting an additional stroke of wing, per second of time, above what is required to sustain the animal on the line of motion, raising him from that line, and also showing a corresponding *decrease* in his velocity.

- No. 8.—The consequence of a still greater celerity of the action of those organs within the same time, enlarging the angle of ascension and exhibiting a more marked falling off in the degree of motion.
- No. 9.—The last one of a series of effects resulting from the force of opposing winds, under the action of the wings at the rate of three strokes per second of time, thus : if the wild duck, for example, be met by a wind of about *twenty-five* miles per hour, he will be thereby raised on the line of No. 7 ; if the velocity of the current of air should increase to about *fifty miles* per hour, he will rise on that of No. 8 ; and if still further augmented to about seventy-five miles per hour, as in a hurricane, he will ascend perpendicularly, as indicated by the broad line of this figure, without any alteration in the movements of his wings.
- No. 10.—The same bird poised in the air on expanded wings by the force of a tornado of *one hundred miles* per hour, and which sustains his weight without any exertion on his part, but, at the same time, gradually drifts him backward, as indicated by the horizontal dotted line.
- No. 11.—The animal whilst in this situation illustrates the principle and exhibits the manner of flying the kite, thus : the force of the wind striking against the under surface of the wings sustains his weight, while the tendency of the latter to descend is precisely similar, in effect, to the power exerted through the string held in the hand of the kite-flyer ; and on a sudden cessation of the wind he will instantly begin to gravitate on the dotted line towards, and thus soon reach the earth at, the figure of the boy.
- No. 12.—The spiral and vertical ascension of certain small birds under the greatest celerity of wing ; this being the only manner in which they can rise by means of those organs alone, on a greater angle than that indicated at figure No. 8.
- No. 13.—The spiral ascension of the buzzard, and some others of the falcon species, on expanded but motionless wings, as already explained.
- No. 14.—The smallest one of the two lines composing this figure shows the true angle on which the wings are raised, with reference to the line of motion in the process of flight proper.

I will now resume the investigation of the more intricate features of this motion, in view of the various figures constituting this diagram, but with reference more particularly to that of No. 2.

Among men of science the chief objection urged against my theory of flight is, that the power of gravitation cannot be made available in imparting *horizontal motion* to a body in the air; and believing, as I do, that the whole process of flight rests upon this principle, and that the horizontal progression of birds on the wing is due to its influence alone, I will attempt to remove this objection, together with all other doubts relative to its truth, by a more elaborate exposition of the principles and the various interesting incidents connected with the production of this admirable motion.

The matters now claiming our particular attention are, first, the structure of the wing; second, the alterations occurring in the superficial condition of those organs by their action in the air, and the effects thereby produced; and third, the *modus operandi* of gravitation and acceleration in producing the horizontal motion of birds on the wing: and which points will be discussed in the order here stated.

It is well known to both the learned and unlearned, that the wings of birds are concave on one side and convex on the other; and it is equally certain that the extreme ends of the quill-feathers are quite elastic. And the points to be more closely examined, are the peculiar condition of the upper and under surfaces of those organs; the nature and the extent of the changes which they undergo by their action, and the direct and incidental effects thereby produced.

It scarcely needs to be mentioned, that there is a marked variation in the general outlines and departures from plane surfaces on both sides of the wings, from the points where they unite with the body to their extreme tips. And on repeated examinations of them I have invariably found, that those portions of the feathers of which they are composed which lie in close proximity to the body are but slightly curved downward, so that, in the case of a wing six inches in width at that point, the usual extent of this flexure is only about one inch. But the curvature in the succeeding quills gradually increases throughout the series, until the depression at the extremity of a wing eighteen inches in length, extends some four or five inches below the top surface at the opposite end near the body. And such is the unvarying

condition, to a greater or less extent, of the top surface of the wings among all birds of extensive flight ; and of course there is a corresponding concavity on the opposite sides, with this difference, however, in regard to the strength of the quills, which, owing to their peculiar form, yield more readily from pressure against the upper than upon the under sides to them.

These peculiarities of the wings of birds are both novel and instructive when wisely considered, there being nothing within the wide range of locomotive organs bearing the least resemblance of them.

And in regard to the nature and extent of the alterations produced in the position of the quills, and consequently the form of the wings by their action in flight, I remark, in the first place, that, in making the downward strokes, from the pressure of the air beneath, the curvature of the back and outer portions of the latter is entirely removed, or, more plainly, the extreme ends of the quills are forced upward to a level position with the solid portions of the wings, but never above that point. And in this straightened condition they exert a considerable influence on the body of the animal, besides that of sustaining it in the air, the direct effect of which is to depress the head below the line of motion ; but a feeling of insecurity in the first efforts at flight of young birds, and the force of habit among the mature ones, compels the former, and enables the latter, alike, to counteract this tendency to derangement of the equilibrium, by a general muscular exertion whilst on the wing; and the consequence is, that, in the struggle between these two influences, there is imparted to the body a pretty strong tendency to rise *obliquely* above the line of motion, upon an angle as indicated by the dotted line at No. 6.

The precise manner in which this occurs is more easily conceived than expressed, farther than the explanation contained in the statement just made goes. For this is one of the most intricate features in the process of flight ; and I can only repeat that the effect stated is produced by the threefold influence of the downward strokes of wing—the force of the straightened quills, in the tendency of each to resume the curved form, acting upon the air, and the muscular exertion of the animal preventing the depression of his head, which latter disturbance, otherwise, would inevitably ensue from this cause.

Secondly, another important temporary change in the area of the wings, is produced by the reverse movement of them, and the reaction

of the quills, and which latter takes place at the instant that the direction of the former is altered ; whereby they not only reassume the natural form but, from the resistance of the air against their top surfaces, they are subjected to a still greater degree of curvature, resulting in a corresponding diminution of the obstruction encountered in raising them, and an equal reduction of the amount of power employed in this movement, compared with what is expended in making the downward strokes.

And I will barely mention here a most singular and interesting incident in this process, connected with the upward movement of the wings, and resulting from the pressure of the air brought in contact with the extended curvature of their under surfaces by the velocity of the body just noticed, and which materially aids in sustaining his weight. An explanation of the manner in which this occurs, together with the probable extent of its influence in flight, will be presently given. And in this connection I will also explain certain effects incidentally arising from the action of the wings and the motion of the animal in flight, but which are not included among the matters that still remain to be discussed, under the enumeration made in the outset. I allude to the manner in which the air is distributed upon the under surface of the wings, and its pressure equalized, in view of the great difference between the extent of the movement and the far greater velocity of their extreme tips, compared with that of the more inward and broader portions of them, and arising from their hinge-like connection with the body; and which latter circumstance is well calculated to lead the mind of the casual observer to believe that there is but little of this kind of force distributed over those parts lying inside of the points of percussion. But not so ; for it will be perceived that the air embraced by the more outward portions of those organs in making the downward strokes is thus forced inward towards the sides of the body, and being thereby slightly condensed it must therefore contribute towards the equalization of the pressure upon the whole of the middle portions of their surfaces. And in regard to the distribution of this force upon those portions lying still nearer to the sides of the animal, it only needs to be stated that the air which is displaced by the moving body passes in two currents under the wings, right and left, whereby it is likewise partially condensed, and thus not only tends to equalize this influence at those points, but, by

its lateral pressure, also affords considerable aid in maintaining the equilibrium of the animal in flight.

This brings us to the consideration of the process of flight on a horizontal line, the extremely intricate nature of which I have sought to illustrate to some extent by means of that portion of the diagram indicated at No. 2.

It will be observed that the central line of this figure is subdivided into sections by a succession of *dotted* and *drawn* lines of equal length, and which, together with the serpentine line, are designed to show the precise relation subsisting between the impulses of the wings and the motion of the body at every instant of time during the progress of the bird through the atmosphere.

Now, let it be supposed that a bird of the form and weight of the canvas-back duck, having one foot area of wing exerted at the rate of three strokes per second of time, after raising himself to the desired elevation upon the ascending line, as seen at No. 1, and adjusting his body in a horizontal position, be moving with the usual velocity of that animal on the wing of one hundred miles per hour upon the central line of this figure, from left to right. It will be perceived that he traverses the first *dotted* section, which is designed to represent the space of twenty-five feet, whilst raising the wings, and thence passing on through the length of the succeeding *drawn* section while making the downward stroke, he thus overcomes the space of fifty feet during the time of one revolution of those organs. And commencing again to raise them from the point opposite the numeral I, the same process is repeated whilst passing onward to II, and thence to III, the distance of one hundred and fifty feet in one second of time. Now, it may be safely inferred, I think, that when the wings are at the highest points of elevation, as indicated by the angles of the serpentine line, the animal is in a situation to begin to depart from the line of motion in the direction successively of the diverging lines A, B, C; because after having traversed the space of twenty-five feet under the influence of his current velocity alone, and with nothing to sustain his weight besides the force of the air exerted against the under surfaces of those organs, as already stated, it is evident that the body must incline to fall in this manner, and that it would soon exhibit a marked departure below that line, but for the check it receives from the downward strokes of wing recurring regularly at

those points. And I deduce from this, that in the process of flight on a horizontal line, the bird begins to depart from the line of motion at intervals of one third of a second of time, and at three successive and equidistant points within the space of every hundred and fifty feet ; while he is as constantly sustained upon that line by a similar frequency of the impulses of the wings, made within the same period of time and occurring at successive intervals, which equally subdivide the same distance.

Another feature of this process, as may be inferred from what has just been said, is the wide difference between the velocity of the body and that of the movement of the wings ; but which may be rendered entirely certain by a glance at figure No. 14, the chief object of which I will now explain :

Adhering to the case of the wild duck, for example, I have ascertained that in raising his wings, their extreme tips describe arcs of circles of about fifteen inches in length, extending from a point seven or eight inches below, to a similar height above, the line of motion, their thin front edges cleaving the air with little or no resistance, describing a line passing from right to left and crossing the path of flight at the centre of the section traversed by the body during the time of this movement, the distance of twenty-five feet, as accurately represented in this figure. And in this manner those organs escape that degree of resistance which would unavoidably result from raising them if the animal progressed very slow, as we know always occurs in rapidly moving, up and down, any such article held in the hand, but without at the same time imparting to it similar horizontal motion. And it is equally certain that whilst being thus raised, the extended curvature of the extreme ends of the quills, under the rapid motion of the body, must meet with a considerable amount of resistance from their contact with the air, and thereby exert a proportionate and sufficient influence to prevent the body from exhibiting any perceptible departure below the line of flight for the time being, as already stated.

It follows from this that the extremities of the wings pass through the space of about thirty inches during each revolution, and altogether about seven and a half feet, per second of time, one half of which only being in the downward direction, and thereby effectively sustaining the weight, while the body within the same period of time traverses the distance of one hundred and fifty feet ; thus showing the velocity

of the latter to be about twenty times greater than that of the former.

Hence, it is certain that in this condition of things any movement of those organs by the bird, designed either to produce or maintain the horizontal motion, would only result in obstructing his progress; for they could not be turned in any direction appropriate to that object, without instantly coming in contact with the impinging atmosphere; and the extent of any such change from their natural position upon, and necessary relation to, the body would be the exact measure of the deleterious effect thereby produced on the motion of the animal.

Now in view of all that has been said relative to the action of the wings, and the effects thereby produced, it is very evident that the popular belief that the horizontal motion of birds in the air is the result of an *oblique* movement of those organs is not only ill-founded, but is likewise clearly at fault with the nature of *propulsion*, as exemplified in all cases of muscular and mechanical locomotion, in conformity with the general application of the second law of motion of Newton. According to this law, all bodies acted upon by a single force move in the line of the impulse by which they are changed from one place or position to another; and it is quite certain that every species of motion, except that of our present inquiry, whether produced by muscular or other power, is referable to this general principle—that *propulsion* is the mode by which the various processes are carried on; and that organs and machinery are the means employed in all cases of prolonged systematic operations of this kind, acting either in a constant rotatory manner, or by a succession of alternate movements, according to the circumstances of each particular case. The truth of this position is too plain to require any argument in its support; and I will here only make a statement of the relation invariably existing between the organs in the one case, and the apparatus in the other, and the results of their action, common to the processes of both muscular and mechanical motion, by way of illustration.

The organs of motion of terrestrial animals occupy a position underneath the body, from the very necessity of the case, and the exertion of them in the process of locomotion, from a similar necessity, results in the *propulsion* of the animal in a straight line with the application of the power employed, or in that of the movement of the organs—the

strength being expended in one direction, while the body moves in the opposite course. And this is the universal condition of the locomotion of all terrestrial and aquatic animals.

And so in the process of mechanical locomotion, whether produced on the surfaces of either the earth or the water—the action of the apparatus designed for that purpose invariably resulting in the *propulsion* of the body in a line corresponding with the direction of the power applied to it. The submerged propeller of the steam-vessel forms no exception to this constant relation betwixt the application of the force and the motion produced, notwithstanding its peculiar form and position; for the principle is the same as in that of the ordinary side wheels of such vessels, the power being expended in a backward direction, while the ship or boat progresses forward. But not so in the process of flight. The direction in which the wings are exerted bears no such relation to the horizontal motion of birds as that which has just been shown to exist in the process of locomotion among all terrestrial animals, properly so called, and by mechanical means. In this case it is unquestionably true that the power is expended in imparting a simple *vertical movement* to those organs, and that, too, at right angles instead of being in a right line with the motion of the animal; and therefore it is next to impossible for the latter to be the product of the former. Hence it is clear that the aerial progression of birds does not result from an *oblique* movement of the wings. And in addition to all that has been said in regard to this matter, I venture the remark that there cannot be found within the whole range of zoology a single animal whose self-progression is effected by a compound or twofold action of a single set of organs of motion. Nature has yet to exhibit such a startling anomaly as that, and the genius of Art would blush at the bare suggestion of the possibility of such a process through the application of the laws of mechanics, either in moving stationary machinery, or in imparting progressive motion to separate bodies. And it does seem to me that nothing in the way of philosophical pretensions could be more strange and unsatisfactory than the teaching of the popular theory on this subject. For the generally received notion, that birds propel themselves through the air by the action of their wings, is involved in the double absurdity of a body moving in a direction forming a right angle with the line of the force applied to it, and also with a much greater velocity within

a given time than that of the organs or apparata by which it is propelled. On the contrary, it seems to me that the requirement of the second law of motion, just cited, or the nature of *propulsion* and the assurance of the strongest and most rational inference, drawn from the highest and most convincing probability, unitedly concur in establishing the *truth* that the vertical action of the wings only serves to elevate and sustain the animal in the air; a truth, moreover, which rests upon the just consideration of the evident impossibility, from the very nature of things, of any other result ensuing from that process.

And here I close my remarks upon the several matters connected with the action of the wings and the various effects thereby produced on the body of the animal while *in transitu*.

And finally, we now come to reconsider more particularly the manner in which the horizontal motion of birds on the wing is produced. And here again, I repeat my first proposition—"That gravitation is the primary and efficient cause of the progression of birds on the wing," and hold that in the process of flight proper there incidentally arises from the force of this principle, and combines with it, a certain amount of what I have called *acceleration*—though the term is hardly admissible, and is employed merely for want of a more suitable one, but which our language does not afford—and to the united effect of these influences the great velocity of those animals is entirely due.

Now, let us again turn to figure No. 2 of the diagram, and in view of it make a further and final analysis of the process by which this motion is produced, and thus if possible ascertain its true cause.

It will be perceived that at the time the bird attains the desired point of elevation, he is moving with all the velocity acquired in making his ascent, and which motion he never loses so long as he continues on that plane in a still atmosphere. And here, after partially relaxing the action of his wings which, as seen in the measurably depressed angles of the serpentine line now takes place, and also adjusting his body in a horizontal position—from both of which circumstances he at once becomes, so to speak, more directly under the influence of gravity than had previously existed in ascending to that point—the true process of flight proper begins, and with it both the origin and influence of acceleration. That the animal whilst thus progressing on the central line of this figure, constantly tends to descend towards a point at a considerable distance in front of him is evident

from the nature of his position in the air, and which arises chiefly from the obstruction which the spread wings present to his perpendicular descent together with his velocity, both of which conspire to disturb the vertical action of gravity upon the body for the time being; and that this inclination towards the earth does, or ought to, accelerate the motion of the animal, it seems to me, is equally certain. And to redescribe this process in the most concise form of words of which I am capable, it occurs thus : The motion of the bird on a horizontal line in a case, for instance, where he starts from an elevated position, such as a tree or mountain top, originates primarily in the constant power of gravitation, the perpendicular action of which is deranged by the intervention of the spread wings and the velocity of the body, so far as to cause the weight to gravitate in a slanting forward direction, as is constantly exhibited in the open air by the descending motion of those animals, whether under the control of the action or nonaction of those organs ; and in this peculiar condition of things, there incidentally arises at first a slight acceleration of the body and which continues to increase until the latter attains a certain degree of velocity, beyond which, from the resistance of the air in front, it cannot go. The precise extent to which this influence enters into the process of flight, would be very difficult to determine ; but in my judgment it is the cause of at least one half of the velocity attained by birds moving on a horizontal line. And this view of the matter may be considerably supported, if not rendered quite certain, by a brief consideration of the direct part which gravitation plays in effecting that result.

Considering it as certain that gravity constantly tends to reduce the bird on the wing below the horizontal line of motion ; and regarding it as true that the combined interposition of the spread wings and the velocity of the body prevent the perpendicular descent of the latter ; then, it follows that the animal must necessarily incline towards the earth on a line ranging a little below the plane of his elevation, or, in other words, he constantly tends to fall in the direction of a point upon the earth considerably in advance of his position in the air, and which point changes, *toties quoties*, with the motion of the body. In this manner only, and to this extent, whatever it may be, the force of gravity is directly concerned in producing the flight of birds ; and hence it becomes more than probable, I think, that under

the action of this principle alone, (and such a thing is possible) the most suitably organized animal for swift motion on the wing would never attain a degree of velocity above fifty miles per hour in a still atmosphere. And therefore, I conclude that *gravitation* and *acceleration*, acting in combination, produce the usual *horizontal motion* of birds of passage, of about one hundred miles per hour.

Entered according to act of Congress in the District Court of the United States for the District of Columbia, by R. O. DAVIDSON, the nineteenth day of May, one thousand eight hundred and fifty-eight.

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